RADIANT TECHNOLOGIES, INC.

Radiant Technologies, Inc.
2835D Pan American Freeway NE
Albuquerque, NM 87107
Tel: 505-842-8007
Fax: 505-842-0366
e-mail: radiant@ferrodevices.com
www.ferrodevices.com

Application Note
Determining the Minimum Charge Accuracy of a Radiant Tester
Rev A

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Author: Joe Evans, Scott Chapman

Introduction:
The Magnetoelectric Response (MR) Task in the Vision Library will run on any Radiant Precision tester from the RT66B to the Multiferroic. The Task measures the amount of charge generated in the ME sample by an applied magnetic field. Typically, these generated charges are very small so the Precision Premier II and Multiferroic testers are more suited for making this measurement. Maintaining accuracy in polarization tests involving magnetic fields is very complex and is subject to many outside factors not under the control of Vision during execution. This is in contrast to the Polarization Vs Voltage Hysteresis Task execution in which Vision has control of all test parameters and error sources with the exception of noise created by external EMF sources. Due to the added complexity of tests implementing magnetic fields, Radiant has generated four application notes focused specifically on optimizing the accuracy of the MR Task execution. The four subject areas are:

1) Measurement accuracy by a Radiant tester for small charge generated by a test.

2) Calibrating the magnetic field sensors used in the MR Task execution.

3) Measuring the Small Signal Capacitance vs. Magnetic Field properties of the sample.

4) Executing the MR Task to determine the magneto-electric coefficient for the sample.

This application note describes, in its next section, the accuracy limitations of the Premier II and Multiferroic testers when measuring total charges below 100 pC. The documents listed below cover the other three subjects listed above.

1) Application Note - Calibrating the Magnetic Field for ME Testing.pdf

2) Application Note - Measuring Small Signal Capacitance vs. H-field.pdf

3) Application Note - Measuring Calibrated ME Samples with the MR Task.pdf.

Please review all four application notes carefully before publishing data acquired with the MR Task.

Small Charges
All Radiant testers employ a virtual ground input on their RETURN connections. A virtual ground circuit maintains its input at electrical ground potential while generating a voltage on its output proportional to the current going into and out of the input. On Radiant testers, the output of the virtual ground circuit is the

input to an integrator circuit that converts those voltages to a cumulative count of the number of electrons that have entered and exited the virtual ground input over the duration of test. For those not familiar with electronic circuit theory, this means that the plot of the hysteresis loop measured with the Hysteresis Task is merely *a plot of the voltage output of the integrator circuit during the test multiplied by the value of the integrating capacitor in the integrator circuit.* No mathematical manipulation or modeling is necessary by Vision. The charge is measured directly by the integrator circuitry.

The frequency of the measurement is irrelevant, provided the test period is slower than the speed of the integrator. This means that a 1 nF capacitor tested at 1 V by the Hysteresis Task on any Radiant tester will generate 1 nC of charge in the integrator circuit whether the test is executed in 1 millisecond or in 1 second. We have placed a current amplifier/de-amplifier in front of the integrator to extend the range of capacitor sizes that the integrator may measure. As an example, if a 1 nF capacitor tested at 2 Volts generates 2 Volts on the integrator output, a 10 nF capacitor tested the same way should generate 20 volts. This is too high to be measured by the integrator circuitry. A divide-by-ten current de-amplifier in front of the integrator will reduce that integrator output voltage back to 2 volts by reducing the amount of charge going into the integrator from the virtual ground input. The primary differences between the individual Radiant tester models are in the speed and charge range of their respective RETURN inputs. Of the testers in Radiant's Precision tester family, the Premier II and Multiferroic testers can measure the fastest and the slowest while detecting the largest and the smallest signals.

Magnetoelectric tests are expected to generate charge values on the order of 100 pC but may produce a much smaller response. Integrator circuits are perfect on paper but not in reality. They are subject to leakage and drift. The amount of leakage and drift during a test will determine the minimum resolution of a test involving small charges. These inaccuracies only affect the measurements at the highest amplification level of the Premier II and Multiferroic testers where the charges are very small. They only apply to tests longer than one second. The discussion in the next section will establish the limits for the Premier II and the Multiferroic when measuring small charges generated by an MR Task execution.

Charge Losses:

There are two sources of charge loss in the Radiant integrators.

1) Captured charge leaking out of the integrator circuit.

2) Small changes in the environment and the ICs of the test circuit that cause the output of the integrator to wander when no stimulus is applied.

The leakage can be measured by executing hysteresis loops on calibrated capacitors generating small amounts of charge. Since the value of the test capacitor and the voltage produced by the DRIVE output across the sample are known precisely, the exact amount of charge that should be expected from a test can be calculated with precision. Any deviation of the results from that value corresponds to a loss.

Below is the Polarization vs Time plot of a precision 10 pF capacitor measured on a Multiferroic tester at 1 Volt with a test period of 1 second.

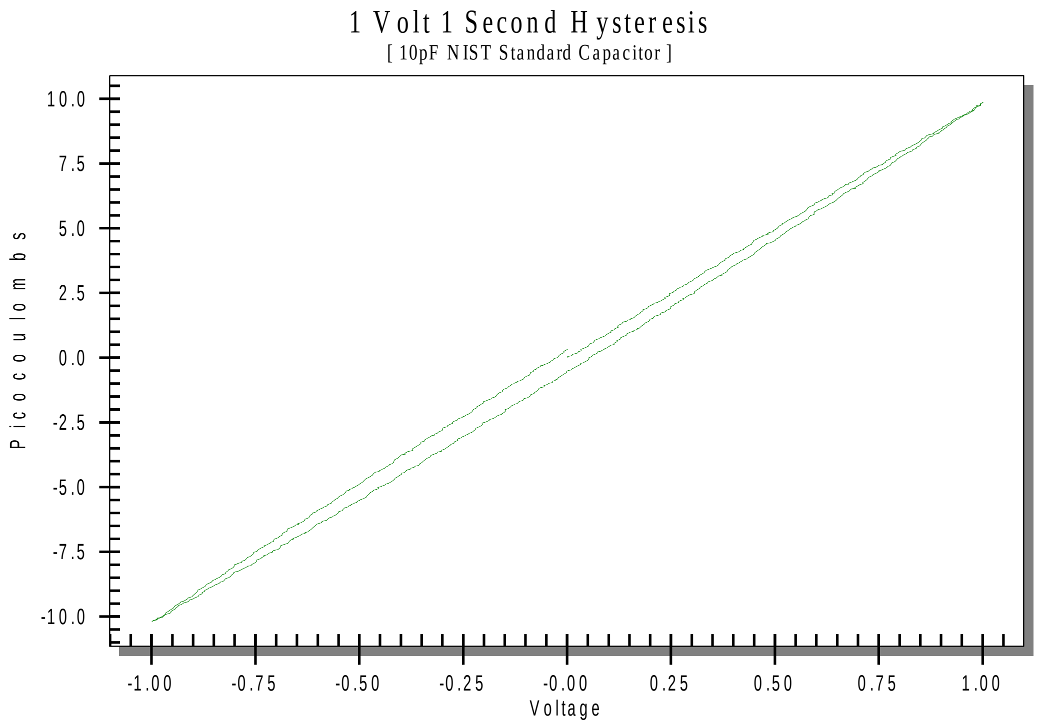

Figure 1: 1 Hz hysteresis loop at 1 Volt for a 10 pF capacitor.

The voltage change from Point 0 to point 255 (the maximum positive voltage) was 1.000 V. That should have generated a charge value of 10.00 pC from the precision capacitor. The tester measured a change in charge of 9.845 between those two points. This is a difference of 0.155 pC yielding an error of 1.5%. Some of that error may arise from random noise. Averaging multiple measurements yields an error of 1.92%. Random noise originating in the tester is small enough not to affect a 10pC measurement.

The same test executed at 10 Hz is shown below. It yields an accuracy of 1.0%.

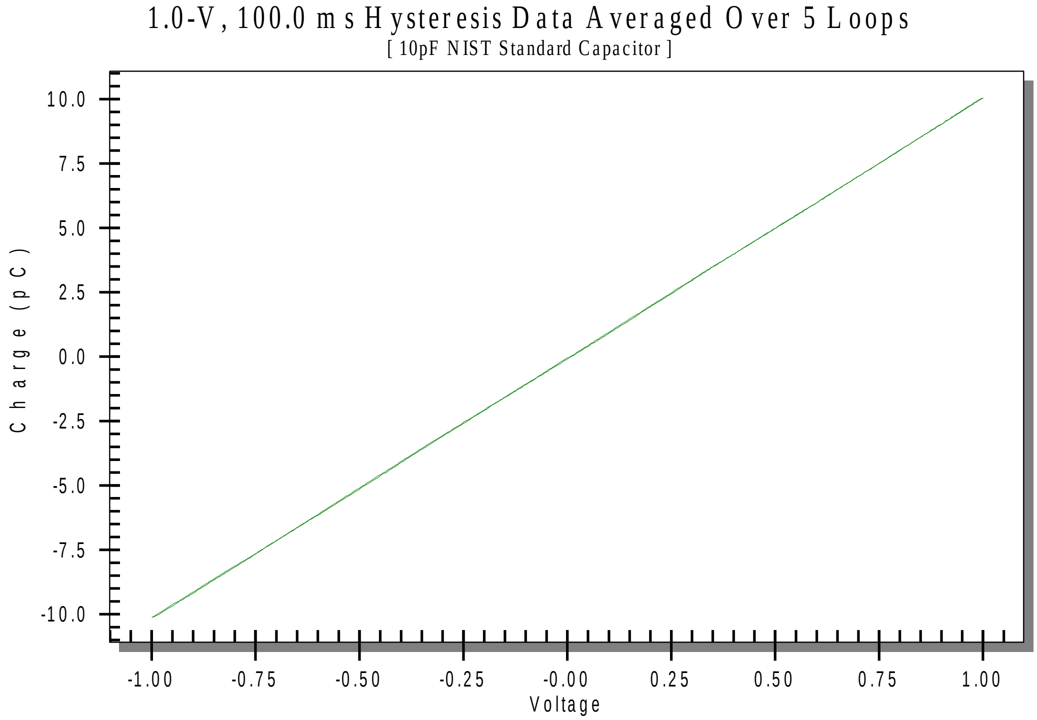

Figure 2: 10 Hz hysteresis loop at 1 Volt for a 10 pF capacitor.

For tests slower than 1Hz, the charge loss is not acceptable for tests involving 10pC or less of charge from the sample, amounting to about 20%. Nevertheless, for samples producing 100pC or more that loss is 2.0% or less.

In summary, because of leakage from the integrator during long tests, the MR Task should not normally be used for tests longer than 1 second unless the sample generates 100 pC or more. Executing the test *faster* than 1 Hz eliminates the effect of integrator leakage. However, typical current amplifiers cannot go faster than 20 Hz driving a Helmholtz coil, putting an upper frequency limit on the MR Task.

Drift:

If a test is executed on a sample at zero Volts, its output will appear to wander from zero. This wandering is caused by any variation in the state of any component in the test circuit plus any change in the external EMF or temperatures during the test execution. Although this error is quite small on the Premier II and Multiferroic testers, it might have an impact on test results smaller than 10 pC.

A zero-Volt test across a sample can be executed in the Hysteresis Task by selecting the "All Zeroes" format instead of the "Standard Bipolar" format for the test. In the "All Zeroes' format, any voltage in the VMax window is ignored and the entire test consists of points at zero Volts. The result of such a test for a Multiferroic tester over 1 second connected to the same calibrated capacitor is shown in Figure 3. Figure 4 shows a photograph of the tester and capacitor.

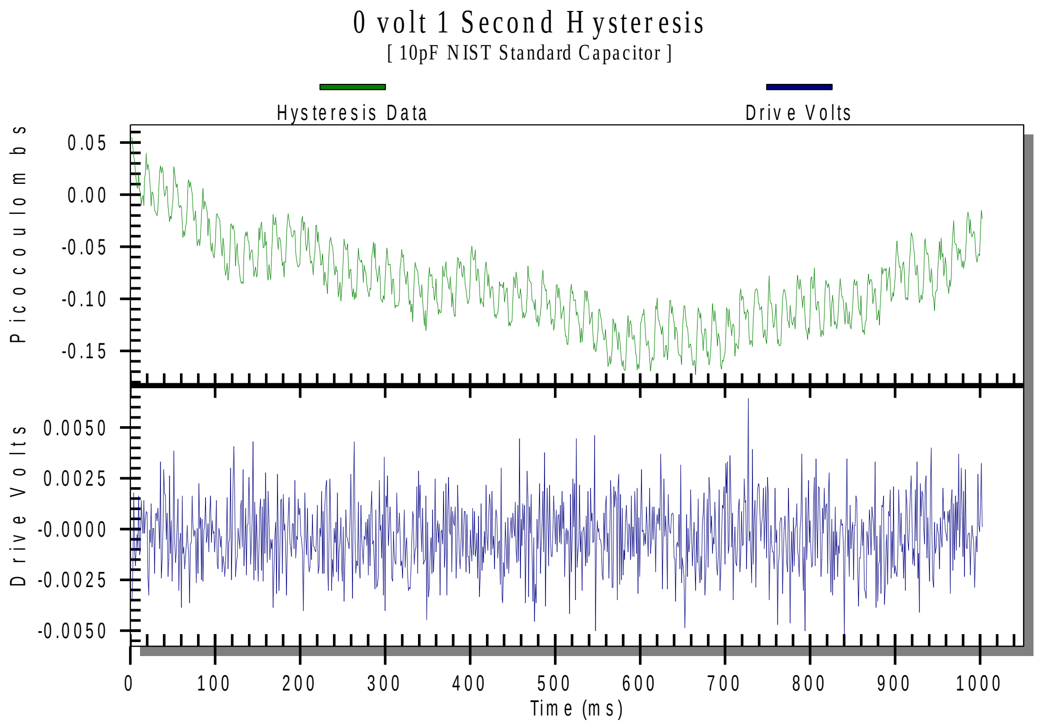

Figure 3: The Multiferroic tester and calibrated capacitor used in this experiment.

Wandering is simply a function of time so the same wandering test executed over 10 seconds simply increases the maximum wander in Figure 3 by a factor of 10.

Figure 4: Test Fixture for the small charge measurements.

Analysis:
Table 1 shows the expected maximum values Radiant anticipates for a Premier II or Multiferroic tester for integrator leakage and zero-Volt wandering at 10 Hz, 1 Hz and 0.1 Hz test frequencies for the MR Task.

	Leakage	Wandering
10 Hz	0.1 pC	50 fC
1 Hz	0.2 pC	150 fC
0.1 Hz	2.0 pC	500 fC

Table 1: Charge leakage and wander vs frequency.

The table indicates that for MR Tasks executed at 1 Hz, if the sample generates 10 pC maximum during the test, there is a reasonable expectation of 3% accuracy or better. For tests at 10 Hz, the accuracy improves to 1%, the minimum specification of these testers for hysteresis loops as all speeds. For tests slower than 1 Hz the accuracy decreases due to leakage effects from the integrator. Nevertheless, the 2% or better accuracy expectation survives for tests where the sample generates more than 100 pC of charge.